VOLUMES I & II

AN ANALYSIS OF ASTRONAUT PERFORMANCE CAPABILITY IN THE LUNAR ENVIRONMENT

VOLUME I

Performance Problems and Requirements for Additional Research

MATRIX

AN ANALYSIS OF

ASTRONAUT PERFORMANCE CAPABILITY IN THE LUNAR ENVIRONMENT

VOLUME I Performance Problems and Requirements for Additional Research

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SUMMARY

This study was concerned with surveying and evaluating research findings reporting expected astronaut performance capability in the lunar environment. Based on the analysis of research reports, problem areas for performance were identified and described and requirements for additional research were defined.

Principal conclusions drawn from the review and assessment of research are that the findings are generallly incomplete, sometimes questionable, and even contradictory, and that astronauts performance will be adversely affected by the lunar environment. The extent of this performance degradation, as well as recommendations for reducing the problems through training, application of engineering judgment, or modification of procedures must await the conduct of more representative, generalizable, and methodologically valid research.

The primary recommendation presented in this report is that an astronaut performance research program be developed immediately which will focus on the research problems, gaps in available data, and the integration of results from different studies. A second recommendation

formulated in this study is that emphasis be placed on the combined effects of multiple factors of the lunar environment rather than relying on analysis of individual effects for describing expected performance.

CHAPTER I.

INTRODUCTION AND SCOPE

As lunar missions of the future are being planned, a great amount of attention is being devoted toward defining the scientific objectives of the missions and experimental procedures to be followed during each mission. Experiments are being designed in the areas of geodesy, cartography, geology, geophysics, geochemistry, astronomy, bioscience, atmosphere measurement, and particles and fields. These experiments have, as their prime objective, the scientific investigation of the lunar surface, subsurface, topography, magnetic fields, radiation and thermal environment, and atmosphere. The majority of the experiments currently being designed place heavy emphasis on a human operator, monitor, and decision maker to select samples, identify unforeseen events, deploy apparatus, and observe instruments and environmental conditions.

Since the role of the man is critical in the exploration and investigation of the moon, it is essential that the capabilities and limitations of an astronaut in the lunar environment be carefully specified. Only a complete understanding of the range of performance capabilities and safety of the astronaut will assure optimal allocation of system functions to man or machine, effective design of equipment which interfaces with the man, and optimal utilization of his time.

Needs for a thorough understanding of astronaut performance and safety requirements on a lunar mission lead to a general requirement for a research program to define capabilities and limitations of astronauts to perform specific missions. This research program should parallel the programs being developed for the scientific areas of lunar geology, geochemistry, etc. The astronaut performance research program should specify individual studies to be performed to identify astronaut capabilities and potential problem areas and safety hazards, and the time sequencing of these studies. The research program is directed toward the dual objectives of defining astronaut performance capabilities in the lunar environment and supporting the man/machine interface design, operational procedures, decision rules, and training requirements associated with these items.

To date all that is known concerning astronaut performance/ safety considerations on the moon has been developed from earth based simulations of the lunar environment or from analytical evaluations of expected capabilities based on available data concerning specific environmental factors. Simulation studies include investigations of astronaut performance in the gravitational, topological, and lighting environment of the moon. The degree of fidelity of these simulations has been a problem primarily due to the constraints imposed by the simulation techniques and due to insufficient understanding of the combined effects of interacting environmental factors. The data concerning the lunar environment, obtained from Ranger, Surveyor, and Lunar Orbiter missions, Soviet Luna missions, telescope observations, photometric studies, and visual reports of Apollo VIII astronauts, describe an environment which in many respects is almost completely novel and which can be expected to adversely affect astronaut performance and safety. The present study was concerned with surveying and analyzing research findings reporting potential problem areas for astronaut performance and citing the type, degree, and effect of expected performance decrements.

The report of this study is presented in two volumes. Volume I contains a summary description of the operational environment, including the lunar environment and the space suit environment, a summary description of mission operations, and a detailed description of problem areas identified for performance of mission operations in the operational environment. This volume also contains an assessment of requirements for additional research, including descriptions of individual studies and definition of the astronaut performance research program. A description of candidate experiments for astronaut performance on the lunar surface, during Early Apollo missions, is presented. Finally, a listing is presented of important conclusions drawn from the study and recommendations associated with each conclusion.

Volume II of the study report is concerned with the detailed data from which evaluations, conclusions, and recommendations included in Volume I were derived. These support data are in three general areas: lunar environment; mission, equipment, and operations; and research findings concerning astronaut performance and safety. The research findings begin with a discussion of simulation techniques and proceed through a survey and analysis of empirical data concerning visual performance, motor performance, spatial orientation, physiological factors, radiation safety, and habitability.

CHAPTER II

DESCRIPTION OF THE OPERATIONAL ENVIRONMENT

On the lunar surface the astronaut will perform mission operations in an environment which is both novel, in terms of earth standards, and constraining, in terms of the utilization of full performance capability. The primary elements of this environment are the lunar environment itself and the pressure suit. Features of the lunar environment which conceivably could influence human performance are: the lunar lighting effects, reduced gravity, surface topology, absence of appreciable atmosphere, temperature levels and variations, and radiation levels. These aspects are described in greater detail in Volume 2 of this report. A summary of the significant features will be discussed in this section.

2.1 Lunar Environment

The most dramatic characteristics of the lunar environment, in terms of effects on astronaut performance, will be the lunar lighting, gravitational field, and surface topography. Due to the almost complete absence of an atmosphere the sunlit moon will exhibit little or no diffusion of light from atmospheric scattering. The effect of this absence of diffusion will be manifested in extremely sharp contours between illuminated areas and shadows. Due to the extreme roughness and porosity of the surface, the reflection of light on the moon is characterized by a strong retro-reflection where the majority of light is reflected back along the path of incidence. The effect of this back scattering in conjunction with the minimal atmospheric diffusion will be such that the amount of light available to the eye will vary for different astronaut look angles. This retro-reflection effect accounts for the uniformity of surface brightness over the surface of the moon, as viewed from earth, and also for the fact that maximum brightness is achieved at full noon where the illumination angle and the angle of observation are nearly coincident.

Due to the low albedo of the lunar surface, only an average of seven percent of the incident light is reflected. In full sunlight the average brightness of the surface is 840 foot lamberts while in full earthshine the average is .0875 ft. L. As indicated in Figure 3 of Volume II (page 23) 840 ft. L. is comparable with the average brightness of the sky on a cloudy day, while .0875 ft. L. corresponds to the minimum light required to read a chart.

The gravitational environment of the moon is approximately one sixth that of earth. The astronaut will therefore weigh one sixth of his earth weight and should be able to apply forces to achieve effects six to seven times greater than those realized on earth for the same forces.

The surface structure or topography of the moon will influence two aspects of astronaut performance: visual performance through its appearance and light reflecting properties, and motor performance, through its cohesiveness, regularity, and slope. The precise nature of the lunar surface is still in question, even with the data available from Surveyor and Russian Luna missions. Some investigators still cling to the dust theory. Hopke, as late as 1967, stated that, based on photometric data, the surface of the moon is very porous and inter-connected, that constituent particles of the microrelief are uniformly fine, and that the cohesion among particles is slight. The surface is therefore covered to an unknown depth by a layer of rock dust arranged in loose clumps very under-dense and compressive.

Largely based on findings from unmanned lunar landings (Surveyor and Luna) the general opinion among scientists today is that the surface is cohesive and has the consistency of wet sand on earth. The importance of determining the precise nature of the extreme surface prior to a manned landing is obvious. It must be assured that the surface can support the LM vehicle, and the exploring astronaut. The possibility that the LM descent engine plume will cause a dust cloud in the final stages of landing which will obscure the astronaut's visual contact with the landing site must be ascertained. Finally, the nature of the surface in terms of its effect on astronaut locomotion and mobility, maintenance of balance and traction, and associated energy expenditures must be determined.

2.2 The Pressure Suit Environment

When operating on the lunar surface the astronaut must contend with not only the constraining factors of the lunar environment, but also with the limitations that his suit places on visual and motion performance. Characteristics of the A7L suit are described in Section 4.2.8.3 of Volume II. While performance standards for this suit are not available, specifications for the A6L suit were acquired from NASA-MSC. The sun visor associated with this suit will transmit 18 to 22 percent of the available light, while the combination of the sun visor, impact, and pressure visors will transmit only 10 percent of the light. The field of view through the visor is 90 degrees upward, 105 degrees downward, and 120 degrees right and left. The neoprene glove assembly is such that the right hand finger dexterity is 65 percent nude hand capability for one half inch pins, and 33 percent for quarter inch pins. Time to activate pushbuttons wearing these gloves was noted to be 40 percent greater than the nude hand capability while for knobs and toggle switches the percentages were 70 and 60 percent greater respectively.

The important factor to consider when analyzing the operational environment and its potential effect on astronaut performance is that even though it is meaningful to assess effects of components of the environment (gravity, lighting, space suit, etc.), in the actual situation the astronaut will be subjected to the total environment. It is important, therefore, to consider the interactive effects of the various components once the influence of each element has been determined.

CHAPTER III

MISSION REQUIREMENTS FOR ASTRONAUT PERFORMANCE

In surveying the multitude of manned lunar explorations, mission segments, and mission operations currently being planned, contemplated, and discussed, a logical distinction was made in terms of short duration early missions and long duration later flights. Stage I missions are characterized by short lunar stay time, limited surface mobility, and emphasis on verification of equipment and human performance as well as acquisition of scientific data. Stage II missions comprise lunar stays ranging from several days to six months. These missions represent an order of magnitude greater than those of Stage I in terms of operational complexity, support requirements, and engineering considerations.

Stage I involves Early Apollo and Apollo. The Early Apollo, the first manned lunar landing, involves a stay time of approximately three hours of which two hours will be spent with an astronaut actually on the surface. Surface activities currently planned for this mission comprise LM vehicle exterior inspection, local area exploration, collection of samples, and deployment of the Early Apollo Scientific Experimental Payload (EASEP). This payload consists of three separate experiments which include the Passive Seismic Experiment, the Laser Ranging Retro-Reflector Experiment, and the Solar

Wind Experiment. Deployment of these experiments will require the astronaut to unstow the packages from the Scientific Equipment Bay compartments of the LM, select a deployment site, carry the packages to the site, assemble the experiment and emplace it on the site. Specific deployment activities and time lines are presented in Tables 8 and 9 of Volume II.

The highest priority of work time on the early Apollo mission should be given to sample collection, according to the NASA Lunar Exploration conference of 1965. The 1967 Summer Study of Lunar Science and Exploration summarized sample collection as selection of geologic samples based on observations of surficial debris and bedrock, acquisition of samples by tongs, drive tube, scoop, or other device, insertion of samples into labeled containers, and storage and return of samples to earth for analysis. The sample collection task places requirements on the astronaut for decision making, pattern recognition, mobility and dexterity, force application, and load carrying.

Apollo missions involve two astronauts on the lunar surface for approximately 24 hours. Actual surface activities will occupy up to eight hours for each crew member. In Apollo, as in Early Apollo, only one astronaut at a time will be on the surface exterior to the LM, with the other crewman in the LM vehicle. The principal astronaut activities during the Apollo mission will be the deployment of the Apollo

Lunar Surface Experiment Package (ALSEP) which comprises an expansion of the EASEP, local area exploration, and sample collection. During the Apollo lunar stay sample collection will involve retrieval of non-cohensive, loose specimens, breaking off features from larger structures, digging up samples of debris, drilling holes through incoherent debris, and excavating fragments. ALSEP consists of two subpackages containing eight separate experiments. The astronaut operations associated with deployment of each experiment have not been finalized. A preliminary operational sequence for the seismic experiment is presented in Table 11 of Volume II.

Stage II includes the various missions of the Apollo Applications Program (AAP). In the early missions crew size will remain at two, however, in later explorations multiple two man or even three man crews will probably be utilized. The primary characteristics of AAP lunar missions are the capability for extended stay and the increased mobility afforded by surface or flying vehicles. This stage will also include missions where alternate configurations of the basic lunar lander, the LM, will be used. These include the LM truck, an unmanned cargo ferry vehicle, and the LM shelter, a living/working compartment for up to two weeks. Primary astronaut activities on AAP missions include extensive exploration and deployment of scientific measurement and data recording devices. These devices include the Emplaced Scientific

Station (ESS), the ALSEP upgraded for longer life and improved performance, the Expanded ESS (EXESS), and the Remote Geogphysical Monitor (RGM) which provides scientific data acquisition and transmission for from 2 to 5 years.

Deployment of these devices as well as lunar exploration itself will be supported by the use of lunar roving vehicles (LRV) and lunar flying vehicles (LFV). These systems are described in greater detail in Chapter III of Volume II. Lunar roving vehicles range from a motorized cart for cargo transportation to closed cabin mobile laboratories (MOLAB) carrying up to a three man crew with living quarters and laboratory facilities. Representative LFV concepts range from one man to three crews with ranges up to 800 KM, altitudes up to 6,000 feet, and velocities up to 500 fps (300 mph).

CHAPTER IV

ASTRONAUT PERFORMANCE CAPABILITIES ON THE LUNAR SURFACE

Subsequent to the analysis of the environment and the identification of operational requirements for future manned lunar missions, this study was concerned with surveying the research findings reporting various aspects of human performance on the moon. The results of this survey and a detailed evaluation are presented in Chapter IV of Volume II of this report. This section is concerned with summarizing the evaluation of these findings and relating them to the operational environment and planned astronaut activities. The objective of this chapter therefore is to integrate research findings with mission requirements and environmental constraints to define the state-of-the-art knowledge of astronaut capabilities on lunar missions as well as to identify problem areas. Performance capability problem areas will be discussed in detail in this chapter, while requirements for additional research will be discussed in detail in Chapter V.

The astronaut operations for prospective lunar missions, summarized in Chapter III of this volume and detailed in Chapter III of Volume II, can be classified into 20 general activities which, while not all inclusive are representative of most of the planned activities for Stage I and Stage II missions. These activities together with indications of visual and/or motor performance capabilities associated with each, are presented below.

Activity	Visual Capabilities	Motor Capabilities
Vehicle Inspection	Visual acuity Perception of form	
Surface Survey	Perception of distance Pattern recognition General vision	
Self Locomotion	Perception of form Spatial orientation	Whole body movements Balance
Observation of astronaut	Perception of pattern Visual acuity	
Sample collection		dexterity balance
Sample Identification	Perception of pattern Perception of form	
Sample storage		weight estimation
Unloading of packages	Visual acuity	weight estimation whole body movements
Experiment deployment	Perception of form Perception of color	arm-hand movements
Package leveling	Spatial orientation Visual acuity	arm-hand movements balance
Use of hammer		arm-hand movements balance
Use of scoop		arm-hand movements balance

MOLAB Deployment		Fine hand movements balance
TV Lens changing		finger dexterity
Vehicle Control	Perception of distance and depth Perception of pattern	
Antenna deployment		balance reach
Lunar drill deployment	Perception of pattern	arm-hand movements balance
Living activities (habitability)		
Maintenance of radiation safety		

As indicated from this list, 18 of the 20 activities have astronaut visual and/or motor performance requirements associated with them. Specific effects of components of the lunar environment on each of these activities are presented in Chapter V of Volume II. Visual requirements can be summarized as general vision or visibility requirements, visual acuity, perception of distance and depth, perception of form and shape, and spatial orientation. Motor requirements can be classified as whole body movements, balance, arm-hand movements, and dexterity.

4.1 Visual Performance Capability and Anticipated Problem Areas

The concensus of opinion among investigators concerning astronaut visual performance in the lunar environment is that the visual problems in the novel, degraded, and still uncertain lighting environment of the moon may be formidable. In general, the low light levels, the homogeneity of surface appearance, highly directional characteristics of lighting, sharp contrasts between light and shadow, and absence of size constancy standards may seriously degrade astronaut performance. The degree to which this visual environment will affect performance capability cannot, at present, be definitively specified due to serious gaps in the research, ambiguities and contradicting results and conclusions, and findings which are questionable from a methodology standpoint. The basic conclusion derived from the evaluation of findings therefore, is that visual performance on the moon will be degraded. Additional research is sorely needed to isolate the causal factors for this degradation, the extent and importance of the degradation for astronaut safety, and the engineering, operational, or training efforts required to minimize or eliminate the problems. Conclusions derived from research results concerning the effects of the lunar environment on visual capability factors (visibility, visual acuity, perception of distance and depth, perception of form and shape, and spatial orientation) are presented below.

4.1.1 Visibility - General Vision

The maximum brightness of the sunlit lunar surface, assuming an average albedo of seven percent, is 840 foot lamberts. This is comparable with the average brightness of the earth on a clear day, i.e., 1,000 ft. L. When viewed through the protective sun visor, impact and pressure visor of the suit helmet which alternates 90 percent of the available light, the maximum surface brightness falls off to 84 ft. L., which is comparable to the average brightness of the earth on a typical cloudy day (Figure 3, Volume II).

- The maximum brightness of the earthlit surface is .0875 ft. L. which is approximately the minimal level for chart reading. Again with the visor assembly only .00875 ft. L. is available to the eye. This is about the minimum recommended by Lewis and Wheelwright (1965) for lunar landings in earthshine. These investigators add that from their findings, brightness levels of less than .04 ft. L. make some operations unsafe. These findings require validation due to the subjective nature of the data but are indicative of the problems associated with low light levels, especially in earthshine conditions.

- Due to the granular porous surface structure and the resultant highly directional retro-reflection of light, the appearance of the lunar scene will vary markedly with differing look angles. When the incident sun angle is 70 degrees from vertical, as it will be for Early Apollo, an astronaut will perceive the maximum available brightness only when he faces away from the sun with a look angle of 70 degrees. Changing his look angle to 85 degrees will reduce the available light to 78 percent of the maximum. When he retains the 85 degree look angle but faces toward the sun he will receive only 3 percent of the available light, which, with the visor in place comprises 2.5 ft. L. As the astronaut views the terrain before him when viewing away from the sun the brightness of the terrain will vary by a factor of 9, when viewing toward the sun the variation is a factor of 3.

- Another important consideration in the effect of look angle on visibility is that when viewing away from the sun with a sun angle of 70 degrees the astronaut will receive maximum light at the eye with a look angle of 70 degrees, which corresponds to an average viewing distance of 16 feet (Table 15, Volume II), and minimal light when looking directly downward (look angle of 0 degrees). Specifically, with the visor in place he will receive 9 ft. L. when looking at the area adjacent to his feet, and 84 ft. L. when looking 16 feet away. The effect of this variation might be to confuse distance judgements since in the earth environment brightness falls off with distance such that brighter objects are judged to be nearer the observer.

- While looking away from the sun represents the optimal viewing situation in terms of levels of available light it is also optimal in terms of total surface area illuminated.

When looking away from the sun shadows will occur on the far side of the object. Looking toward the sun places the shadows on the observer side of the object and reduces the total area of illumination.

- Another problem in looking toward the sun is that this situation could put the sun in the field of view of the astronaut. While accidental brief viewing of the solar disc is not sufficient to cause permanent retinal damage it will affect the adaptive state of the eye. This effect could be such that it would take from 11 to 16 seconds to readapt to a level required to perceive an object of .06 ft. L. brightness.

- In order to compensate for variations in surface brightness with changes in look angle as well as to increase the illuminated area in the field of view, artifical light sources will probably be used. In order to ensure that the astronaut controls the direction of illumination he should carry a portable light source with him which should be mounted on his body to free his hands for other activities. MSC has investigated chest mounted and wrist mounted lights for this purpose. A problem arises from the use of such lights since, due to the fact that most of the light reflected by the lunar surface is directed back along the path of incidence, the artificial illumination could become a source of glare. The intensity of the light should be such that it enables the astronaut to see into shadowed areas while at the same time not be so intense as to degrade visual performance. In order to deliver 10 ft. L. to the eye the intensity of the source must be 1400 ft. candles. The field of view of the illumination source must also be determined. It should be great enough to ensure adequate viewing of local terrain yet as small as possible to conserve power.

The problem of placement, intensity, number, and field of view of artificial light sources has not received sufficient attention to date. A feasible approach would be to carefully plan the limits of astronaut excursion on early missions and position lights on the LM vehicle, on light standards, and on the astronaut's body to ensure that all portions of that area are visible.

4.1.2 Visual Acuity

- The effects of the lunar lighting environment on visual acuity are generally unknown. The primary factor will probably be the low light level which will degrade acuity so as to increase the size of the smallest perceptible object (Table 15, Volume II). While the data presented in Table 15 are for a sun angle of 0 degrees, it is logical that for a sun angle of 70 degrees and viewing away from the sun acuity will be most degraded for surface terrain nearest the astronaut and will improve up to a maximum at a distance of 16 feet from the observer after which it falls off again.

This apparent contradiction of acuity improving with distance is due to the variations in available light with different look angles, noted above.

- Some investigators assume that acuity on the moon will be greater than on earth due to the minimal atmospheric attenuation. There is some evidence for improved astronaut visual acuity during Gemini flights 5 and 7 as well as during astronaut Cooper's Mercury mission. Findings however, are inconclusive and conflicting assumptions have been drawn from the same data.

4.1.3 Perception of Distance and Depth

- The primary cue in the judgement of distance is the size constancy of familiar objects which serve as standards for such judgements. In the totally novel environment of the moon such standards will not be available. Judgements of the size of an object in this environment without reference standards, is extremely difficult, and resultant errors in the judgement of distance to an object of unknown size will probably be great.

- It is unclear from the literature whether the astronaut will consistently err in distance judgments toward over-estimation or underestimation. Since no other reliable reference is available for distance judgements the astronaut may use the horizon as a standard. Conditioned as he is to making distance judgements on earth, the astronaut could overestimate distances on the moon due to its smaller size and foreshortened horizon. Other investigators assume that the absence of an atmosphere and the resultant transparency of the medium will lead to gross underestimates of distance.

- The extreme contrast between lighted terrain and shadow should severly degrade the perception of depth and slope. The almost total absence of brightness gradations from light to total shadow combined with the directional nature of lunar reflectivity will lead to a confusion of cues for the perception of depth since on the moon brightness depends more on the relation of angle of illumination and angle of observation than on distance as such. Judgements that brighter objects are nearer, conditioned by earth experience, could be erroneous in the lunar environment. The degree to which depth perception will be degraded by characteristic lunar lighting effects has not been specified and requires more extensive investigation.

4.1.4 Perception of Form and Shape

- The extreme contrast between light and shadow on the moon will also degrade the astronaut's perception of form, shape, and pattern. His form judgements must be based totally on the illuminated portion of the object since the brightness of shadowed areas will be too low for him to perceive any detail. The effect of the contrast conditions and directional nature of reflected light will be to degrade terrain recognition and orientation, as when the astronaut compares his visual scene with photographs of the local area. Depending on the relationship of his look angle, the sun angle, and the location of objects of interest, these objects could take on dramatically different appearances. The extent to which these effects lead to confusion and disorientation must be studied more intensively, as well as the degree to which the problems can be eliminated through artifical light sources.

4.1.5 Spatial Orientation

- Research findings indicate some degradation in the ability of observers to estimate the vertical in reduced gravity. The size of the observed decrement is usually small and conclusions as to its practical effect are not available in the literature. The primary effect of degraded ability to judge the vertical will probably be manifested in the ability to judge slant and slope. This ability is probably more essential to the control of lunar roving vehicles which are limited in terms of terrain slope than it is to self locomotion by the astronaut.

- Maintenance of spatial orientation depends on the agreement between visual information and vestibular information. The degradations of visual performance expected as a result of contrast conditions, low light levels, and directionality of reflected light, coupled with decrements in vestibular information resulting from reduced gravity stimulation could lead to disorientation, although some investigators postulate that the vestibula will be sufficiently stimulated in the lunar environment (Gaume and Kuehnegger, 1962). Research is needed which investigates the combined effects of the lighting and gravity environments on observer orientation.

4.1.6 Summary of Visual Problems

As indicated in the discussion presented above, and detailed in Volume II, the astronaut faces many potential problems in the lunar lighting environment. The specification of the precise degree to which these problems will result in performance degradation is sorely lacking in the research literature. Taylor (1964) asserted that predictions of visual performance on the moon should not be attempted without validation in a realistic environment wherein representative lighting conditions are simulated. The few simulation studies reported in the literature are usually so limited in terms of fidelity and control as to make conclusions tentative at best and highly questionable. The retro-reflective property of lunar luminance, which probably will be the single most important determiner of astronaut visual performance on the moon, has not been included in any visual simulations to date. It is strongly recommended that simulation facilities be designed for careful investigation of astronaut performance in the lunar environment which includes the combined effects of collimated low light levels, low albedo, directional retro-reflection, extreme contrast conditions, and presence of glare sources such as the solar disc on sunlit earth.

4.2 Astronaut Motor Capabilities in the Lunar Environment

The principle motor capabilities which could be affected by the lunar environment are whole body movements, hand-arm movements, and weight estimation.

4.2.1 Whole Body Movements

- The natural lunar gait has been postulated to comprise a lope rather than a walking gait at an average velocity of 10 feet per second. The average earth walking speed is about 4 feet per second.

- Running speed on the lunar surface will probably be lower than on earth due to the reduced traction afforded by the surface.

- Results from lunar gravity simulations indicate that as compared with earth standards the astronaut on the moon will cover five times the same distance in any time period, at nine times the speed for the same distance and at eleven percent of the time for the same distance.

- While the majority of studies were concerned with the capability of the astronaut to walk, run, and jump in a lunar gravity environment, findings reported in these studies are questionable since they generally did not investigate the combined effects of surface topography or traction, lighting environment, and gravity on human performance. Many did not even investigate the effects of pressurized suit conditions. Some results were reported which indicate that the simulation technique employed itself significantly affects the results. Methodological problems such as small samples of subjects and inadequate controls also render much of the data questionable. Most of the simulation techniques limit the freedom of lateral motion which possibly stablizes the walking subject to a degree greater than in the actual situation. While an astronaut might be able to move over the lunar surface at a rate greater than on earth, his ability to maintain equilibrium while performing this locomotion has not been established and, in the reduced gravity environment, can indeed be questioned. It is logical to assume that as locomotion speed increases, stability and control of balance decreases, especially on rough terrain. Loss of equilibrium on the moon could seriously affect astronaut safety since body contact with the surface could cause suit damage, bodily injury, or equipment (such as life support) failure. Based on the above, a statement of astronaut self locomotion performance capabilities is meaningless until the possible effects of all elements of the environment have been determined. To base such statements on gravity effects alone and to disregard suit effects, surface roughness effects, and lighting effects is not only meaningless, it is misleading and potentially detrimental to astronaut actual performance and safety.

- Two schools of thought exist as to the effect of the lunar environment on energy expenditures associated with lunar self locomotion. One group of investigators assert that, due to the reduced gravity, less work will be required for lunar walking than observed in the earth environment. Empirical data are reported from one-sixth gravity simulation studies which indicate that the metabolic cost of walking on the moon will range from 28 to 48 percent lower than earth standards.

A growing body of opinion among investigators holds the exact opposite hypothesis, that the energy to be expended in performing lunar locomotion will be greater than reported on earth. This effect is assumed to be due to increased muscular activity in providing restoring forces normally provided by gravity, to excessive limb movements, and to the leaping gait assumed for lunar locomotion. The hypothesized increase in metabolic rate for lunar walking has also been assumed to be due to the requirement to use new muscle groups for locomotion, which can probably be releived through training. Increases in metabolic rate ranging from 15 to 34 percent have been reported for walking in a simulated lunar gravity environment as compared with earth locomotion.

While this question is still largely unresolved, it would appear that the case presented by those claiming an increase in metabolic rate associated with lunar as opposed to earth walking is more reasonable and justifiable. Research results reported by both factions are questionable due to inappropriate or absence of controls; however, it is logical to assume that, given the constraining influence of the suit, the uncertainty of the terrain in terms of visual presentation and traction, the importance of maintaining balance, and the use of new muscle groups, astronauts will tend to restrain their locomotive movements rather than to freely maneuver over the surface with abandon. This application of restraint on muscular activity will probably lend to increased energy expenditures.

Since the question of metabolic rates associated with lunar locomotion affects the design of environmental control systems, in terms of quantity of expendibles and heat dissipation rates, it is probably better to err toward the side of over-estimation rather than underestimation of energy requirements. In the absence of valid data for either position it is therefore recommended that increased metabolic rates be assumed for lunar exploration until proven otherwise. The quantity of increase must be determined from simulation and/or from carefully controlled astronaut experiments in the actual environment.

4.2.2 Arm-hand Movements

Little data exist pertaining to the effect of lunar gravity on arm-hand movements. One study reports an increase in time to perform basic maintenance tasks in lunar gravity over earth condition on the order of 25 percent. Additional research is required to establish the range of arm-hand movement capability in the lunar environment under realistic gravity and suit conditions.

4.2.3 Perception of Weight

On earth the perception of weight is due to proprioceptive stimulation and judgements of the amount of force required to counter the gravitational force associated with the weight. In the lunar environment an adaptive period will probably be required wherein the astronaut learns to adjust his standards to the new gravity condition. This can and should be facilitated through pre-flight training.

4.3 Habitability

- The problems for lunar shelter habitability revolve around three general areas: life support, volume and compartmentalization of shelters, and support of living activities. Little research has been reported on requirements for free volume for lunar shelters. For orbital missions recommendations for two-man crew, thirty-day missions have ranged from 95 to 240 cubic feet per man. Lunar shelters are not as constrained as orbital stations since astronauts can egress the shelter with more ease and frequency than is true of the orbital flights. The availability of lunar surface activity which provides the astronaut with exercise and diversion should reduce his needs for free volume within the shelter. One study performed at Marshall Space Flight Center reported that two subjects could function adequately in a simulated MOLAB for an 18 day period with only 58 cubic feet per man available in free volume. They were not confined to the vehicle throughout the period but were given opportunities to perform daily simulated lunar excursions exterior to the vehicle (Haaland, 1966).

The specification of requirements for free volume, shelter compartmentalization, and support for living activities must await further research. The effects of the lunar environment on performance of living activities has not been determined.

CHAPTER V

REQUIREMENTS FOR ADDITIONAL RESEARCH

From the problem areas for astronaut performance capability identified in Chapter IV it is apparent that much additional research is required before definitive statements of astronaut performance can be made. Shortcomings of available research include their lack of fidelity to the actual situation, disregard for combined effects of different variables, presence of arti-facts in the data due to the simulation technique, and methodological problems of sample size and experimental design. The approach of studying the effects of individual environmental factors, such as gravity, in and of itself is appropriate, however, conclusions based on results must recognize that the interacting effects of such variables as terrain and lighting with gravity must be studied before performance capability can be estimated.

Based on the research problems cited above it is recommended that additional research be undertaken to establish the precise effects of lunar environment factors on performance, and that such research be planned in terms of an integrated research program where study outputs and objectives are identified and relationships among study areas clearly specified.

It is not recommended that the vast literature already accumulated concerning astronaut performance on the lunar surface be discarded and investigation of effects begin from scratch. Much of the available data are useful in identifying problem areas. What is now needed is a complete specification of the extent of each problem area and its practical effect on performance capability as well as research leading to recommendations for techniques to reduce the problem. Appropiate techniques for problem reduction could include engineering design, operational procedures, or training.

5.1 Visual Problem Area Research Requirements

Specific visual studies as well as recommended variables and methodology are presented below.

Study 1 Effect of directional lighting

This study should investigate the effects of retro-reflection of light on visual performance. Distance judgements, visual acuity, and form recognition should be studied in a simulated lunar environment which includes directional reflected light of levels representative of the lunar situation and collimated to simulate solar illumination.

Dependent variables - accuracy of distance judgements, size judgements, form matching, and visual acuity.

Independent variables - Astronaut look angles, lighting angles, lighting levels, surface albedo.

Control variables- pressure suit representative of the lunar suit and visor.

Expected Results - it is anticipated that visual performance will vary with the relationship between look angle and sun angle and sun position such that maximal capability will be noted for the situation where the light source is behind the subject and look angle and sun angle are coincident.

Study 2 Parameters of artificial light sources

Integrated into the simulation facility used in Study 1 a study of location, number, field of view, and intensity of artificial light sources should be performed to identify parameters of these lights.

Study 3 Distance judgements in the lunar environment

Integrated with the simulation facility used in Study 1 should be a means of simulating the reduced atmosphere and foreshortened horizon of the moon. Surface features should be representative of those expected in the lunar environment. With this up-graded facility the ability of astronauts to judge distance accurately can be determined empirically. This study should be followed up with a similar investigation performed on the actual surface.

Dependent variable - accuracy of distance judgements

Independent variables - horizon location, look angle, sun location and sun angle, lighting levels, and surface albedo.

Control variable - pressure suit and visor.

Study 4 Perception of Depth

To the visual simulation should be added contrast conditions which approach those expected on the moon. Using this facility, the capability of the observer to make relative distance judgements and to accurately perceive depth will be investigated.

Dependent variables - accuracy of relative distance judgements.

Independent variables - degree of shadow, location of shadow, look angle, sun angle, sun location, lighting levels, and surface albedo.

Control variables - suit and visor.

Study 5 Spatial orientation

The combined effects of the lunar visual environment and the gravitational environment on observer capability to estimate the vertical and judge degree of slant and slope must be determined. Subjects must be presented with lighting conditions representative of those expected on the moon while under one sixth earth gravity. This study will therefore require a combination of visual simulation facilities with gravity simulation techniques. Since locomotion on the part of the subject is not required and due to the short time required for each judgement, it is recommended that parabolic flight be selected as the gravity simulation method. Subjects would be presented with standard objects misaligned from the vertical by a specified amount and asked to assess the degree to which the objects depart from the vertical. Their judgements will be made against a visual background which simulates the lunar scene in terms of directionality of reflected light, surface appearance, and contrast.

Dependent variables - accuracy of vertical judgements

Independent variables - look angles, sun angles, lighting levels, sun location, surface albedo, and surface roughness.

Control variables - 1/6 gravity, pressure suit and visor.

Study 6 Total visual performance in the lunar environment

This study will integrate the variables and conditions of Studies 1 through 5 to investigate the combined effects of lighting conditions on visual performance.

5.2 Motor Problem Area Research Requirements

Specific studies of astronaut motor capabilities in the lunar environment are described below.

Study 1 Astronaut walking capability

A definitive investigation of astronaut walking capability in the lunar environment has not yet been performed. This study should assess the interactive effects of gravity, surface traction, and surface roughness on walking ability. Measures of stability should be included to determine the degree to which the astronaut can maintain balance. Different gaits and speeds should be investigated to determine which is optimal in terms of comfort, energy expenditure, and safety.

Dependent variables - stability, energy expenditure, walking rates.

Independent variables - degree of surface cohesiveness, roughness, and slope.

Control variables - pressure suit and gravity condition.

Study 2 Astronaut walking capability - II

This study will incorporate a simulated lunar visual environment with Study 1 above.

Study 3 Astronaut load carrying/lifting capability

This study will investigate limitations and techniques of load carrying and lifting in a simulated lunar environment, similar to Study 1.

Dependent variables - stability, energy expenditures, walking rates.

Independent variables - load weights, techniques of carrying, lifting points.

Control variables - pressure suit and gravity condition.

Study 4 Arm-hand movement capability

The objective of this study will be to assess the effects of the lunar gravitational and lighting environment on astronaut capability to perform standard arm-hand operations.

Dependent variables - accuracy of motions and time to perform.

Independent variables - look angles, light angles, sun location, equipment albedo.

Control variables - tasks, pressure suit, and gravity conditions.

Study 5 Gravity simulation fidelity investigation

This study will attempt to establish the fidelity of lunar gravity simulation techniques by comparing results obtained using different techniques and isolating areas where the technique introduces arti-facts into the results.

5.3 Astronaut Performance Research Program

In order to ensure adequate planning and performance of required research as well as to make maximum use of data acquired in the actual lunar situation, an astronaut performance research program is recommended which is described in Figures 1 and 2. This program is directed toward establishing astronaut performance capability for Stage I and Stage II missions by defining the study areas to be researched, the sequencing of these studies, interrelationships among studies, and interrelationships between earth based simulation studies and investigations conducted during actual lunar missions. For each study area the objectives, inputs, outputs, methodology, and ultimate goals are described. Study 1 of Stage I comprises the present study which will serve as the baseline for defining requirements for additional research.

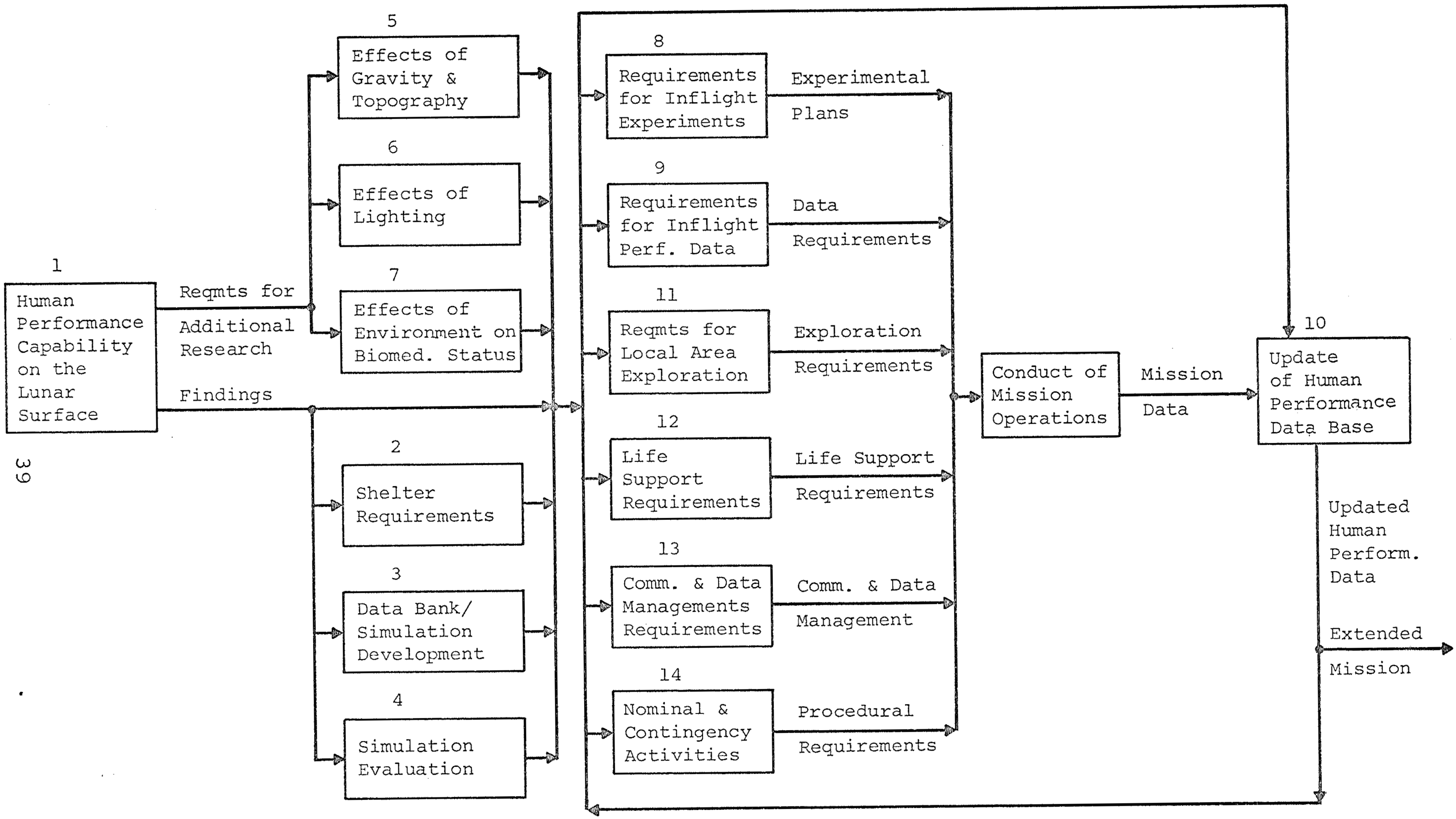

FIGURE 1. ASTRONAUT PERFORMANCE/STATUS RESEARCH PROGRAM STAGE I MISSIONS

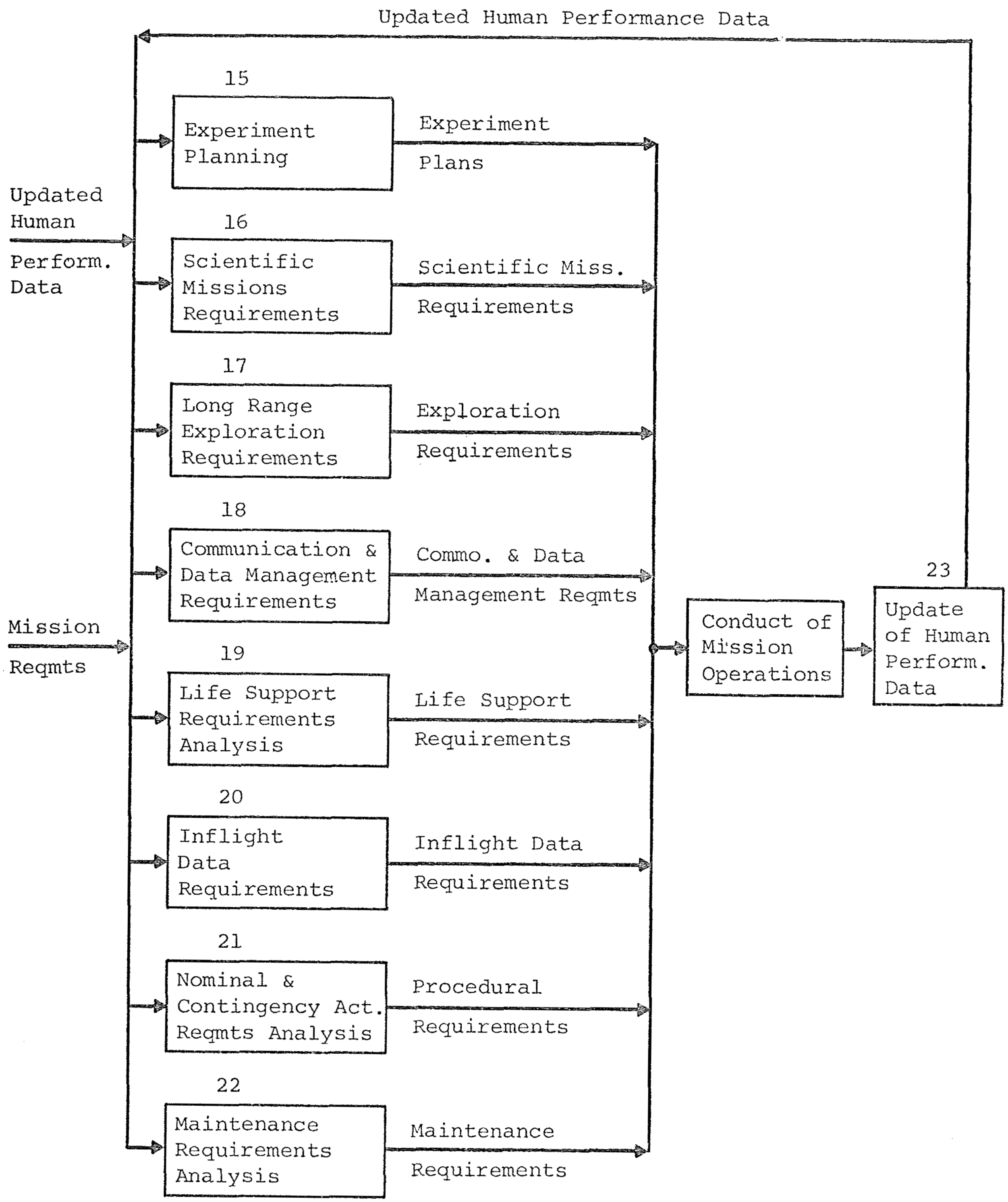

FIGURE 2. ASTRONAUT PERFORMANCE/STATUS RESEARCH PROGRAM STAGE II MISSIONS

STAGE I. MISSIONS (UP TO 14 DAYS)

1. Survey literature and determine research requirements for establishing astronaut perceptual-motor performance capability in the lunar environment.

A. Specific Objectives

- Review literature on effects of lunar environment on astronaut performance.
- Relate findings to anticipated mission activities.
- Identify problem areas for performance.
- Identify requirements for additional research.

B. Inputs

- Existing literature on effects of lunar environment.
- Discussion with cognizant personnel.

C. Outputs

- Classified, evaluated research findings.
- Anticipated problem areas.
- Requirements for additional research.

D. Methodology

- Literature search.
- Mission analyses.
- Lunar environment analysis.
- Astronaut performance capability analysis.

E. Ultimate Goals

- Provide data base of research results for mission planning.

- Provide identifications of problems areas of design of equipment on performance of procedures or training.

- Provide requirements for additional research where gaps in present literature exist or where existing findings are deemed questionable.

2. Determination of design requirements for lunar shelters.

A. Specific Objectives

- Develop requirements for lunar habitability systems.

- Develop design guidelines for shelter design and layout and equipment arrangement.

B. Inputs

- Specific research reported in study 1 on effects of the lunar environment on human performance.

- Mission requirements including crew size, mission duration, and astronaut operations and equipment.

C. Outputs

- Design guidelines for habitability system equipment.

D. Methodology

The worksteps to be completed in developing habitability system requirements and design guidelines include the following:

1. Identification of representative mission requirements and constraints.

2. Determination of requirements for shelter configuration/compartmentalization.

3. Determination of free volume requirements for compartments.

4. Determination of work/rest cycle requirements.

5. Determination of illumination requirements.

6. Determination of EC/LS requirements.

7. Determination of decor requirements.

8. Determination of requirements for equipment arrangement/packaging.

9. Development of requirements and design guidelines for astronaut living operations, including sleep, taking nourishment, waste elimination, rest and relaxation, exercise, locomotion, maintenance of personal hygiene, equipment care and housekeeping, and medical-dental care.

10. Development of shelter and equipment mockups.

11. Verification of requirements and design guidelines through the simulation of habitability functions, using mockups.

E. Ultimate Goals

- Develop guidelines for habitability systems for short term missions.
- Identify habitability problem areas.
- Determine minimum volume requirements.

3. Development of an astronaut/lunar surface computer data bank and simulation.

A. Specific Objective

- Provide a data bank which is easily updated, modified, and assessed.
- Develop a simulation which will model the man performing candidate lunar operations for specific missions and predict astronaut performance capability.

B. Inputs

- Research findings from study 1.
- Habitability requirements from study 2.

C. Outputs

- A lunar surface data bank.
- A simulation model for evaluating additional banks.

D. Methodology

This system will comprise a data bank of research findings, engineering concepts and approaches, design data, and recommendations and design guidelines, and a simulation model appropriate for predicting the effects of variations in shelter and equipment design configuration on human performance and biomedical status. The efforts to be completed in developing this Data Management System include the following:

1. Development of general system description.
2. Specification of data input subsystem.
3. Specification of data accession subsystem.
4. Development of performance, safety, and biomedical data bank.
5. Development of a lunar environment data bank.
6. Specification of data retrieval subsystem.
7. Specification of the mission simulator.
8. Specification of a report generator.

E. Ultimate Goals

- Provide a data base describing astronaut performance capability and physiological status on the lunar surface which is easily accessed, updated, and modified.
- Provide a computer model of the astronaut to predict performance and biomedical status for any specific mission.

4. Development of fidelity requirements for lunar surface simulation studies.

All of the empirical evidence relating to astronaut capabilities and limitations on the lunar surface is based on some simulation of the environment. A problem exists in defining the fidelity to be incorporated into such simulations and in evaluating existing findings in terms of the fidelity of the simulation situation.

A. Specific Objectives

- Establish guidelines for defining degree of fidelity required.
- Evaluate currently available simulation techniques and facilities in terms of their fidelity.
- Develop guidelines for selecting simulation techniques and facilities.
- Formulate recommendations for new improved techniques and facilities.

B. Inputs

- Simulation requirements.

C. Outputs

- Simulation evaluation techniques.
- Simulation evaluations.

D. Methodology

The approach to be taken in this study is to develop a checklist and supplementary data book to assist simulation planners or evaluators in determining the degree of fidelity required or the effects of a specified fidelity level.

E. Ultimate Goals

- Provide guidelines for planners of lunar surface simulations for selection of simulation techniques.
- Provide evaluations of simulation techniques for verification of reported findings.

5. Specification of effects of lunar gravity and terrain on locomotion, maneuvering, limb/body mobility.

A. Specific Objectives

- Determine effects of lunar gravity on psychomotor performance (research requirements identified in Study 1).
- Determine performance capability in simulation 1/6 g environment and lunar topography, soil composition and friction, in hard suit with PLSS.

B. Inputs

- Specific research requirements identified in Study 1 relating to effects of gravity and terrain.

C. Outputs

- Research findings tailored to fill gaps in knowledge identified in Study 1.

D. Methodology

- From study 1 - identify specific mission related operations for which adequate gravity and terrain effect data are not available.
- Develop gravity - terrain simulation facility.
- Conduct mission related operations using simulation facility.
- Record, analyze, and evaluate data, relate findings to available research results.
- Establish phychomotor performance capability, verify equipment design, procedures, and astronaut training.

E. Ultimate Goals

- Advance the body of knowledge concerning astronaut psychomotor capability.
- Identify problem areas associated with mission operations in lunar gravity and terrain.

- Develop design criteria for equipment and requirements for redesign.

- Develop operational procedures and techniques.

- Develop training requirements.

6. Specification of effects of lunar lighting on astronaut sensory-perceptual performance.

A. Specific Objectives

- Determine the effects of ambient light brightness, backscattering of light, minimal atmospheric diffraction effects, etc., on astronaut visual performance (research requirements identified in Study 1.).

B. Inputs

- Specific research requirements identified in Study 1 relating to effects of lunar lighting on visual performance.

C. Outputs

- Research findings tailored to fill gaps in knowledge identified in Study 1.

D. Methodology

- From Study 1 - identify specific visual tasks for which adequate lighting effects data are not available.

- Develop lunar lighting research facility.

- Simulate visual tasks using lunar lighting research facility.

- Record, analyze, and evaluate data, relate findings to available research results.

E. Ultimate Goals

- Advance the body of knowledge concerning astronaut performance capability in the lunar environment.

- Identify problem areas associated with mission operations in the lunar environment.

- Develop design criteria for equipment and requirements for redesign.

- Develop operational and precautionary procedures and techniques.

- Develop training requirements.

7. Specification of effects of the lunar environment on astronaut biomedical status.

A. Specific Objectives

- Determine effects of radiation, atmosphere, and temperature and crew biomedical status.

- Identify problem areas for crew biomedical status.

B. Inputs

- Requirements for additional research from Studies 1 and 2.

C. Outputs

- Results of analytic evaluation.

D. Methodology

- Determine parameters of the lunar physical environment.

- Specify astronaut operations and workloads.

- Perform literature search of environment effects studies.

- Identify problem areas where lunar environment can adversely effect biomedical status.

E. Ultimate Goals

- Identify biomedical data to be recorded in flight.

8. Specification of human performance experiments to be conducted while on the lunar surface.

A. Specific Objectives

- Develop perceptual-motor performance experiments to be conducted on the lunar surface.

B. Inputs

- Perceptual-motor performance capabilities expected in lunar environment (from studies 1, 5, & 6).

- Indications that verification of data is still required.

C. Outputs

- Experiment objectives, procedures, required hardware, schedules, data recording, transmittal, or storage requirements, and training requirements.

D. Methodology

- Identify perceptual-motor areas most amenable to or in need of lunar surface experimentation.

- Identify requirements for lunar surface experimentation - develop candidate experiments.

- Develop experiment selection criteria.

- Select experiments by applying criteria to candidate experiments.

- Develop objectives of selected experiments.

- Develop experimental design, procedures, data management requirements.

- Develop training requirements.

- Develop experimental sequencing, scheduling requirements, crew utilization requirements.

- Generate plan for experiments.

E. Ultimate Goals

- Identify lunar surface perceptual-motor experiments.

- Provide justification for experiments.

- Provide detailed experiment plans.

9. Determine human performance and biomedical status data to be monitored during a mission and evaluated after the mission.

A. Specific Objectives

- Specify crew performance and biomedical status data to be recorded and monitored during a mission and evaluated after the mission.

B. Inputs

- Operations to be performed during the mission - from mission planning.
- Expected problem areas in the conduct of operation - studies 1, 5, 6, & 7.

C. Outputs

- Data to be recorded and monitored, frequency of monitoring, frequency of update, allocation of monitoring functions to the crew or to mission control, uses to be made of data such as prediction of future capability, aid in abort decisions, etc.

D. Methodology

- Review mission plans and schedules.
- Identify expected problem areas.
- Identify data reflecting the existence and extent of problems.
- Determine monitoring requirements - frequency, duration, sample rate.
- Allocate monitoring functions to crew members or to mission control.
- Develop decision rules associated with monitored data - when to continue, abort, modify schedules, await later developments, etc.
- Identify data to be subjected to post-flight analysis.

- Develop baseline data to serve as standard for in-flight data.

E. Ultimate Goals

- Ensure crew safety and mission success.
- Validate human performance capability estimates.
- Provide for real time re-scheduling through prediction of future capability or effects of present capability.

10. Update of lunar surface human performance capability and biomedical data bank based on previous mission findings.

A. Specific Objectives

- Validate and update the lunar surface human performance data base.

B. Inputs

- Human performance data base from studies 1, 5, 6. Biomedical data - Study 7.
- Results of experiments described in Study 8.
- Human performance data obtained in Study 9.

C. Outputs

- Updated lunar surface human performance data base.

D. Methodology

- Review results from lunar surface experiments (Study 8.) and data collected on performance of mission related activities (Study 9).
- Relate these data to the human performance data base (Studies 1, 5, & 6).
- Validate, modify, and update the data base.

E. Ultimate Goals

- Make maximum use of available data.

- Continually update the human performance data base as more data become available.

11. Specification of requirements for local area exploration.

A. <u>Specific Objectives</u>

- Develop human performance requirements, equipment design criteria, and operational procedures for local navigation, mapping, and survey operations.

B. <u>Inputs</u>

- Human performance capabilities identified in Studies 1, 5, & 6 for early mission, and Study 7 for later flights.
- Specific mission exploration requirements including purpose, extent, available navigation schemes, available mapping, topography, and survey systems, etc.

C. <u>Outputs</u>

- Human performance requirements associated with local area exploration.

D. <u>Methodology</u>

- Review exploration requirements for the specific mission.
- Determine crew operations for exploration.
- Determine astronaut capability to perform operations.
- Conceive of alternate approaches for navigation, mapping, survey, etc.
- Develop requirements and crew capability estimates for:
  - celestrial navigation
  - navigation by line of sight - distance estimation, landmark recognition.
  - navigation by beacon - light, sound.

- navigation support from orbiting CSM and/or mission control.

- navigation by gyro compass.

- topography mapping procedures.

- survey equipment.

- locomotion devices on aids, walker, roving vehicle, flying vehicle.

- disposition of mapping data.

- location of sites for long term mission bases.

. Integration exploration requirements with other mission requirements.

. Perform simulation of exploration functions.

E. Ultimate Goals

. Development of first stages of lunar exploration plan.

. Validation of exploration techniques, procedures, equipment.

12. Specification of mission related life support requirements.

A. Specific Objectives

. Develop life support requirements for specific missions.

. Update habitability requirements for specific missions.

B. Input

. Human performance capabilities identified in Studies 1, 2, & 5 for initial missions, Study 10 for later flights.

. Biomedical performance capability identified in Study 7 for initial missions, Study 10 for later flights.

C. Output

- Life support system design criteria, habitability system specifications.

D. Methodology

- Review mission requirements as duration, operations, crew size, etc.

- Review human performance and biomedical status data.

- Integrate mission requirements with performance/biomedical data.

- Develop requirements for life support/habitability systems.

    - pressurized living area - compartmentalization - volume requirements.

    - sleep requirements.

    - work/rest cycles - off duty requirements.

    - nourishment - waste management.

    - medical facilities

- Perform simulation of life support functions.

E. Ultimate Goals

- Provide requirements for life support/habitability systems for short term missions.

13. Specification of requirements for communications and data management.

A. Specific Objectives

- For specific missions develop requirements for inter-crew communications, communications with orbiting CSM, and communications with mission control.

- For specific missions develop requirements for data acquisition, recording, analysis, evaluation, transmittal, and storage.

B. Input

- Human performance capabilities from Studies 1, 5, & 6 for early missions, Study 10 for later missions.

C. Output

- Communication/data management requirements for specific missions.

D. Methodology

- Review communication/data management requirements from mission plans.
- Review human performance capability data.
- Develop nominal communications usage rules.
- Develop contingency communications requirements.
- Develop requirements for:
  - data acquisition - geologic samples, TV images, photographs, electronic signals from sensors.
  - data recording - lunar orbital, or earth.
  - data recording - lunar, orbital, or earth - computer requirements, etc.
  - data transmittal - frequency, duration, quantity.
  - data storage.
- Perform simulation of communications and data management functions.

E. Ultimate Goals

- Communication plan and data handling requirements.
- Sizing of data storage facilities.

14. Specification of astronaut requirements for conduct of nominal and contingency mission activities.

A. Specific Objectives

- Develop requirements for performance of specific mission activities.

B. Inputs

- Mission requirements
- Human performance and biomedical data from studies 1, 5, 6 & 7 for early flights, Study 10 for later missions.

C. Outputs

- Validation of operational requirements and equipment design criteria.

D. Methodology

- Review mission operational requirements (i.e. Alsep operations).
- Relate operational requirements with human performance capability.
- Identify problem areas associated with performance of operations, procedures or equipment design.
- Recommend modifications of procedures and/or design.
- Simulate nominal and contingency operations.

E. Ultimate Goals

- Equipment design for operability, maintainability, and safety.
- Verification of operational requirements.

STAGE II. MISSIONS (14 DAYS TO 6 MONTHS)

15. Human performance requirements for conduct of lunar surface experiments.

A. Specific Objectives

- Specify human performance capabilities and limitations associated with lunar surface experiments.

B. Inputs

- Specific experiments as defined by mission plans.
- Human performance data from short term missions (Study 10).
- Human performance data from earlier long term missions (Study 23).

C. Outputs

- Experiment plans updated to account for lunar performance capability.

D. Methodology

- Review lunar surface experiments to be conducted, which could include:
  - long term effects of lunar environment on human performance/status.
  - verification of experimental power supply status, life support systems, etc.
  - lunar base setup and utilization.
  - effects of environment on all reproduction, microorganism mobility, etc.
  - development of lunar resources.
  - validation of exploration devices, aids, maps, etc.
  - human adaptation to long term gravity, illumination effects.

- Determine astronaut involvement in conduct of experiments.
- Review equipment design criteria or develop design criteria.
- Review operational procedures or develop procedures.
- Review of development of experimental design, data management procedures, etc.
- Update experimental plans.
- Simulate conduct of experiments.

E. <u>Ultimate Goals</u>

- Ensure optimal interface of astronaut with experiment equipment.
- Provide guidelines for experiment scheduling, monitoring, conduct.

16. Perform lunar performance requirements analysis for scientific missions.

A. <u>Specific Objectives</u>

- Specify human performance capabilities and limitations associated with scientific missions.

B. <u>Inputs</u>

- Specific mission requirements.
- Human performance data from short term missions (Study 10).
- Human performance data for earlier long term mission (Study 23).

C. <u>Outputs</u>

- Verification of equipment design for operability and safety.
- Verification of procedures.

D. Methodology

. Review mission related scientific studies including:

  - use of lunar based telescope systems.
  - geology, geochemistry, geophysics.
  - study of lunar atmosphere, radiation, magnetic fields.

. Review human performance capabilities related to scientific missions.

. Develop equipment design criteria for design for operability and safety.

. Develop guidelines for procedures and techniques.

. Simulate performance of scientific missions.

E. Ultimate Goals

. Ensure optimal interface of astronaut with scientific equipment.

. Provide guidelines for scientific mission scheduling, monitoring, conduct.

17. Perform long range lunar exploration requirements analysis.

A. Specific Objectives

. Develop human performance requirements, equipment design criteria, and operational procedures for long range navigation, mapping, and survey activities.

B. Inputs

. Specific mission requirements.

. Human performance data from short term missions (Study 10) and long term missions (Study 23).

. Requirements analysis for local area exploration (Study 11).

C. Outputs

- Long range exploration requirements.

D. Methodology

- Perform exploration systems analysis.
- Perform exploration systems requirements analysis.
- Allocate exploration functions to astronaut or machine performance (remote maneuvering unit).
- Develop design criteria for man performed functions.
- Develop a simulation study of exploration functions.
- Develop exploration procedures and techniques.
- Develop requirements for conducting exploration missions simultaneously.

E. Ultimate Goals

- Development of long range exploration, navigation, and mapping systems capability and data.

18. Requirements analysis for communications and data management on long term missions.

A. Specific Objectives

- Develop requirements for communications and data management.

B. Inputs

- Specific mission requirements.
- Human performance data-short term missions (Study 10) and long term missions (Study 23).
- Requirements analysis for short term missions (Study 13).

C. Outputs

- Long term mission communications and data management requirements.

D. Methodology

- Develop communications usage rules.
- Develop contingency mode communications requirements.
- Develop requirements:
  - data acquisition.
  - data recording - on site capability.
  - data analysis - computer programming available.
  - data transmittal.
  - data storage.
- Establish guidelines for data management on site as opposed to data transmitted to earth for reduction, analysis, and evaluation.
- Establish facility requirements for preparing, processing, and analyzing:
  - geologic sample data.
  - video and photographic film data.
  - biological response data.
  - crew performance data.
  - sensor data.
- Simulate communications/data management operations.

E. Ultimate Goals

- Specification of communications/data management equipment design and procedures.

19. Requirements analysis for life support systems for long term missions.

A. Specific Objectives

- Develop requirements for long term mission life support systems.

- Develop requirements for long term missions habitability systems.

B. Inputs

- Specific mission requirements.
- Human performance data - short term missions (Study 10). and long term missions (Study 23).
- Requirements analysis for short term missions (Study 12).

C. Outputs

- Long term mission life support system requirements.
- Design for habitability requirements.

D. Methodology

- Review mission requirements such as duration, operations, crew size, etc.
- Review human performance and biomedical status data.
- Integrate mission requirements with performance/ biomedical data.
- Develop requirements for life support/habitability systems.
  - pressurized living area - compartmentalization - volume requirements.
  - facility layout.
  - portable life support systems. PLSS, umbilical, lunar roving vehicle systems.
  - sleep requirements.
  - work/rest cycles - off-duty requirements.
  - facility - equipment sharing among crews.
  - nourishment - waste management.
  - medical - dental facilities.

- refurbishment requirements.

- Perform simulation of life support habitability functions.

E. Ultimate Goals

- Support design for operability, safety, and habitability for long term missions.

20. Determine human performance and biomedical status data to be monitored during a mission and evaluated after the mission.

- Same as Study 9 for short term missions.

21. Specification of astronaut requirements for conduct of nominal and contingency mission activities.

- Same as Study 14 for short term missions.

22. Perform requirements analysis for maintenance, repair, and construction systems.

A. Specific Objectives

- Determine human performance capability to perform maintenance, repair, and construction activities.

B. Input

- Specific mission requirements.

- Human performance data for short term mission (Study 10.) and long term mission (Study 23).

C. Outputs

- Maintenance, repair, and construction requirements.

D. Methodology

- Review mission oriented failure effects analysis.

- Determine crew capabilities to perform troubleshooting, replacement, and repair.

- Specify test equipment, tools, and support equipment for maintenance and repair.
- Specify facility requirements for maintenance and repair.
- Determine crew capabilities to perform construction activities.
- Specify tool and support equipment requirements for construction.
- Specify construction material design, design of fasteners, procedures of material deployment, sub-assembly, erection, and installation.

E. Ultimate Goals

- Development of lunar surface maintenance philosophy.
- Development of facility requirements.
- Development of construction requirements.

23. Update of human performance capability data base.

A. Specific Objectives

- Validate and update lunar surface performance capability data base.

B. Inputs

- Human performance data recorded from Studies 15 thru 21.

C. Output

- Updated human performance data base.

D. Methodology

- Review data for specific missions.
- Relate data to the human performance data base.
- Validate, modify, and update the data base.

E. Ultimate Goals

- Make maximal use of available data.
- Continually update the data base as more data become available.

CHAPTER VI.

HUMAN PERFORMANCE EXPERIMENTS FOR EARLY APOLLO

Study number 8 of the astronaut performance/status research program presented in Chapter V is concerned with specifying human performance experiments to be conducted on the lunar surface. This chapter will outline selected candidate experiments to be included in early Apollo to provide performance data in the actual gravitational and light environment of the moon.

The constraints placed on experiment selection are as follows:

1. Experiments will require a minimum of new equipment and procedures.
2. Experiments will minimally impact the astronaut timeline.
3. Only one astronaut will be assumed to be on the surface at any one time.
4. Astronaut experiment operation will involve only the setup of apparatus, acquisition of data, storage of data, and breakdown of apparatus. No data reduction, processing, or analysis will be conducted.

Candidate experiments will be designed to investigate one or both of two general performance capability areas: the ability of the astronaut to effectively receive and process sensory information; and, the ability of the astronaut to perform whole body movements in the lunar gravitational field.

Sensory Requirements

Candidate experiments which are designed to investigate the capability of the astronaut to effectively receive, process, and utilize sensory information fall into two general categories, - visual experiments and non-visual experiments. Visual experiments include studies directed toward defining the effects of the lunar lighting environment on such behaviors as: color differentiation, color naming, perception of the vertical, perception of distance and depth, and estimation of area. Only one non-visual experiment has been identified which entails the perception of weight.

The titles, objectives, variables, data acquisition and recording requirements, number of astronauts, time estimates, astronaut location, and equipment requirements for candidate experiments are presented on the following pages.

SENSORY EXPERIMENT CANDIDATE 1

TITLE:	Color differentiation in the lunar environment.
OBJECTIVE:	Determine astronaut's ability to differentiate colors.
METHOD:	By comparing one of the Munsell standard color charts with each of a series of comparison charts the astronaut will indicate which of the alternatives matches the standard hue, value, and chroma. This procedure will continue for a number of matchings.
INDEPENDENT VARIABLES:	Location of the sun - directly to the rear, directly in front, and to the side of the astronaut.
DEPENDENT VARIABLES:	Degree of deviation from accurate match along each of three dimensions - hue, value, and chroma. Time to complete the judgment.
DATA ACQUISITION AND RECORDING:	All responses made by the astronaut will be verbal and these responses will be recorded on the mission tape recorder with a time reference.
NUMBER OF ASTRONAUTS REQUIRED:	One for each session.
TIME ESTIMATES:	Thirty seconds for setup, 10 seconds each match.
ASTRONAUT LOCATION:	Lunar surface.
EQUIPMENT REQUIRED:	Spot photometer, Munsell color cards.
PROCEDURES:	The astronaut will measure the brightness of each chart with a photometer after orienting himself with respect to the sun, as directed by the experiment procedures, while standing on the lunar surface. He will then match a selected number of color charts, turn to the next orientation and complete the same procedure with a different set of charts.

SENSORY EXPERIMENT CANDIDATE 2

TITLE:	Color naming on the lunar surface.
OBJECTIVE:	Define the effects of lunar lighting on the astronaut's ability to identify color by name.
METHOD:	The astronaut will expose Munsell color charts following a pre-arranged sequence and identify each chart by color name within the constraints of some fixed number of choices.
INDEPENDENT VARIABLES:	Location of the sun - directly to the rear, directly in front, and to the side of the astronaut.
DEPENDENT VARIABLES:	Consistency of color naming behavior on the lunar surface with responses elicited on earth.
DATA ACQUISITION AND RECORDING:	Verbal responses stored on tape.
NUMBER OF ASTRONAUTS REQUIRED:	One for each session.
TIME ESTIMATES:	Thirty seconds for setup, ten seconds each trial.
ASTRONAUT LOCATION:	Lunar surface.
EQUIPMENT REQUIRED:	Spot photometer, Munsell color charts.
PROCEDURES:	Same as those cited for Experiment 1.

SENSORY EXPERIMENT CANDIDATE 3

TITLE:	Peception of the upright.
OBJECTIVE:	Determine capability of the astronaut to visually perceive the upright.
METHOD:	One astronaut on the lunar surface will set an erect rod a given angular deviation from vertical. The astronaut in the LM, on viewing the rod through the LM window, will attempt to estimate the offset from vertical.
INDEPENDENT VARIABLE:	Degress of deviation from vertical.
DEPENDENT VARIABLE:	Accuracy of judgments.
DATA ACQUISITION AND RECORDING:	Voice response recorded on tape.
NUMBER OF ASTRONAUTS REQUIRED:	Two - one experimenter and one subject.
TIME ESTIMATES:	Three minutes setup, 10 seconds run time per session.
ASTRONAUT LOCATION:	One in LM and one on lunar surface.
EQUIPMENT REQUIRED:	Specially constructed variable position rod and deviation measuring scale. Photometer.
PROCEDURES:	The EVA astronaut will set the rod a known distance from LM and will offset it from vertical a given number of degrees. The LM astronaut will then view the rod and judge whether it is or is not aligned to the vertical. This procedure will be completed for at least 30 settings.

SENSORY EXPERIMENT CANDIDATE 4

TITLE:	Perception of depth and distance.
OBJECTIVE:	Determine capability of astronaut to visually judge distances.
METHOD:	Assuming that both astronauts will not be on the lunar surface at the same time, the external astronaut will judge the distance to a fixed number of terrain features. These estimates will be recorded by the astronaut in the LM. After the judgments the external astronaut will measure the actual distance to each of the features from the estimation location.
INDEPENDENT VARIABLES:	Location of the sun with respect to the terrain feature.
DEPENDENT VARIABLES:	Differences between actual distances and perceived distances.
DATA ACQUISITION AND RECORDING:	Data acquired and recorded by LM astronaut.
NUMBER OF ASTRONAUTS REQUIRED:	Two - one experimenter and one subject.
TIME ESTIMATES:	One minute setup, five minutes per trial including measurement of actual distance.
ASTRONAUT LOCATION:	Lunar surface.
EQUIPMENT REQUIRED:	Measuring device, photometer.
PROCEDURES:	Measure the brightness of a feature. Estimate the distance to the feature. Measure the distance to the feature.

<u>SENSORY EXPERIMENTER CANDIDATE 5</u>

TITLE:	Estimation of area in the lunar environment.
OBJECTIVE:	Determination of the degree to which astronauts can make equal area judgments in the lunar environment.
METHOD:	The subject on the lunar surface will move a rod across the face of geometrically shaped two dimensional figures. The astronaut in the LM will instruct him to stop displacing the rod when he judges the figure to be bisected such that equal areas appear on the two sides of the rod.
INDEPENDENT VARIABLES:	None
DEPENDENT VARIABLES:	Deviation of area judgments from actual areas.
DATA ACQUISITION AND RECORDING:	Voice responses recorded on tape.
NUMBER OF ASTRONAUTS REQUIRED:	Two - one on the lunar surface serving as experimenter - one in the LM serving as the subject.
TIME ESTIMATES:	Two minutes setup, ten seconds per judgment.
ASTRONAUT LOCATION:	One in LM and one on lunar surface.
EQUIPMENT REQUIRED:	Special figures, means of bisecting figures, photometer.
PROCEDURES:	See method

SENSORY EXPERIMENT CANDIDATE 6

TITLE:	Perception of weight.
OBJECTIVE:	Determine the effects of lunar gravity on weight perception.
METHOD:	Subjects will heft bags containing rock samples and make absolute judgments of weight. The collection, deposit in bags, weighing, and storage of these samples is already an integral part of the Apollo mission.
INDEPENDENT VARIABLES:	None
DEPENDENT VARIABLES:	Measures of the degree and direction of the error between actual and perceived weight as compared with judgments obtained on earth.
DATA ACQUISITION AND RECORDING:	Voice response recorded on tape.
NUMBER OF ASTRONAUTS REQUIRED:	One per session.
TIME ESTIMATES:	Ten seconds per judgment.
ASTRONAUT LOCATION:	At time of judging - either on lunar surface or in LM.
EQUIPMENT REQUIRED:	None in addition to existing equipment.
PROCEDURES:	See method.

Motor Experiments

Candidate experiments which are designed to provide information on astronaut capability to maneuver about the lunar surface can be described in one experiment where the astronaut walks a measured distance with and without loads and one in which he performs bending, kneeling, and squatting maneuvers while on the surface.

MOTOR EXPERIMENT CANDIDATE 1

TITLE:	Astronaut maneuverability on the lunar surface.
OBJECTIVE:	Measure astronaut maneuverability capability on the lunar surface.
METHOD:	The astronaut will walk a measured course at a leisurely speed, return at the same speed, pick up a load of known weight, and traverse the same course. This procedure will be repeated for at least two types of terrain - flat terrain and gradual slopes, and one course will require the astronaut to walk toward and away from sun while the other requires a course which places the sun to the side.
INDEPENDENT VARIABLES:	Courses with respect to the sun position relative to the astronaut and with respect to the terrain. Four courses of the same distance will be required which include: . flat terrain in line with the sun . flat terrain with sun to the side . sloped terrain in line with the sun . sloped terrain with sun to side
DEPENDENT VARIABLES:	Physiological measures such as respiration rate and heart rate. Time to complete the traverse.
DATA ACQUISITION AND RECORDING:	All data will be measured through the biomedical measuring system and through the use of a stop watch operated by the astronaut.
NUMBER OF ASTRONAUTS REQUIRED:	One at a time.
TIME ESTIMATE:	Approximately 20 minutes per astronaut.
ASTRONAUT LOCATION:	Lunar surface.
EQUIPMENT REQUIRED:	Stop watch.
PROCEDURES:	See method.

MOTOR EXPERIMENT CANDIDATE 2

TITLE:	Astronaut performance of kneeling, bending, squatting.
OBJECTIVE:	Measure energy expenditures associated with whole body movements.
METHOD:	Astronauts will perform kneeling, bending, and squatting with and without mobility aids.
INDEPENDENT VARIABLES:	Type of terrain - loose or firm. Use of mobility aid (staff, etc.).
DEPENDENT VARIABLES:	Respiration rate and heart rate. Time to perform each operation.
DATA ACQUISITION AND RECORDING:	Biomedical data recorded automatically. Time data recorded by the astronaut.
TIME ESTIMATES:	5 minutes per astronaut.
ASTRONAUT LOCATION:	Lunar surface.
PROCEDURE:	The astronaut will kneel, squat, and bend at the waist while using and not using mobility aids. Time to perform each operation and energy expenditures will comprise performance measures.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

A. General

<u>Conclusion 1</u> From the survey and analysis of research results concerning astronaut performance capability on the lunar environment it is concluded that much is yet to be learned relative to specific performance capabilities. The findings reported are generally incomplete, sometimes questionable, and even contradicting.

<u>Recommendation 1</u> It is recommended that additional research be conducted which emphasizes the interactive effects of different elements of the environment rather than merely the specific effects of individual factors.

<u>Conclusion 2</u> While human performance on lunar missions is continually cited as a prime contributor to mission success, the missions are usually structured to provide data concerning the moon itself with little or no attention to acquiring information concerning astronaut performance in the environment.

<u>Recommendation 2</u> An astronaut performance research program is recommended which will structure the research requirements concerning specific aspects of astronaut performance and which will ensure that all potential problem areas are resolved prior to manned lunar missions. This program will also define the activities of astronauts while on the surface

which will lead to a verification of simulation results and an upgrading of simulation fidelity.

Conclusion 3 Much of the available data reflecting expected astronaut performance in the lunar environment is questionable due to problems with experimental design and methodology, and simulation fidelity.

Recommendation 3 It is recommended that a study of lunar environment simulation techniques be undertaken as soon as possible to delineate the fidelity requirements and capabilities of available techniques to meet these requirements.

Conclusion 4 Many of the reported problem areas for astronaut performance can be reduced or eliminated through engineering design, modifications in procedures, and training.

Recommendation 4 The astronaut performance research program should be concerned not only with defining astronaut performance capability but also with identifying approaches to reduce the observed problems.

B. Visual Performance

Conclusion 1 Visual performance on the moon could be severely degraded due to the directionality of reflected light, low light levels, extremely sharp contrast between light and shadow, absence of a diffusing atmosphere, and absence of size constancy standards.

Recommendation 1 The nature and degree of degradation as well as techniques to reduce it must be determined from additional research. Specific studies are recommended in Chapter V of this volume.

Conclusion 2 The appearance of the lunar scene will vary with the relationship of look angle and illumination source angle.

Recommendation 2 Research is required to determine the degree to which visual performance varies with look angle, sun angle, and sun location. Research is also required to specify procedures or training requirements to offset problems.

Conclusion 3 Astronauts will require artifical light sources to enhance the lighting environment and fill in shadows.

Recommendation 3 It is recommended that, at least for Early Apollo, all excursions and traverses be preplanned and artifical source number, location, intensity, and field of view be specified based on simulation of these excursions.

Conclustion 4 Acuity on the moon will probably not differ from that observed on earth in terms of angular subtense but will differ in that it will depend on the relationship of sun location, sun angle, and look angle.

Recommendation 4 Research is needed to validate this conclusion.

Conclusion 5 Perception of distance and depth will be degraded, however, the exact nature and degree of this decrement has not been determined.

Recommendation 5 A lunar lighting simulation is required which contains a representative horizon, surface features, albedo, and contrast. With such a simulation facility the effects of this lighting environment in the perception of distance and depth can be established.

Conclusion 6 Due to the extreme contrast on the lunar surface, as well as the directional nature of reflected light. The perception of form, pattern, and shape will probably be degraded.

Recommendation 6 The degree of this degradation as well as the effect of artifical light sources must be investigated.

Conclusion 7 Astronauts will probably have some difficulty in estimating the vertical in the lunar environment.

Recommendation 7 Research is needed to verify this conclusion which includes a representative simulation of both the lighting environment and the gravity environment.

Conclusion 8 The risk of retinal burns from accidently viewing the sun is minimal even without the visor since the intensity of the sun in the vacuum of space is a factor of 10 less than the minimum level associated with retinal damage.

Recommendation 8 The requirement for the visor should be re-evaluated since it results in a transmission of only 10 percent of the available light.

C. Motor Performance

Conclusion 1 Due to difficulties in methodology and fidelity, characteristics of the lunar gait cannot be determined from current research.

Recommendation 1 It is recommended that lunar self locomotion be investigated in a simulation facility which has no lateral restriction, which simulates the surface topography, and which includes a representation of the visual environment.

Conclusion 2 The effect of the reduced gravity on the moon is probably to increase the metabolic rate associated with self locomotion.

Recommendation 2 The conservative approach of assuming an increase in metabolic rate should be employed until actually investigated in a carefully controlled, representative experiment. This approach places primary emphasis on astronaut safety and life support requirements.

D. Habitability

Conclusion Due to the availability of the lunar surface for exercise, astronauts will require less free volume in lunar shelters than they would need in orbital space stations.

Recommendation Research is required to establish the free volume and habitability requirements for lunar shelters.

E. Radiation

<u>Conclusion</u> The radiation environment of the moon should pose no great problems provided adequate monitoring of dosages and solar flare acitvity is assured.

<u>Recommendation</u> Radiation monitoring should qualify as a high priority activity, at least during early missions.